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Complexity of the channel is beneficial for time reversal communications. After multichannel combining, each user signal is processed with a single channel decision feedback equalizer (DFE) to remove any residual intersymbol interference (ISI) and compensate for channel fluctuations during the packet transmission. This same approach can be applied in a synthetic aperture context where multiple transmissions (separated spatially) substitute for multiple receive elements. As an alternative to the passive time reversal technique, an iterative equalization and decoding approach also has been developed for recovering information transmitted through a shallow water communication channel.

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Abstract

Complexity of the channel is beneficial for time reversal communications. After multichannel combining, each user signal is processed with a single channel decision feedback equalizer (DFE) to remove any residual intersymbol interference (ISI) and compensate for channel fluctuations during the packet transmission. This same approach can be applied in a synthetic aperture context where multiple transmissions (separated spatially) substitute for multiple receive elements. As an alternative to the passive time reversal technique, an iterative equalization and decoding approach also has been developed for recovering information transmitted through a shallow water communication channel.

Research Summary

In passive time reversal, the channel response $h_i^j(t)$ from each source (or user) (superscript j) to each receiver element (subscript i) is obtained from a channel probing waveform prepended to each data packet (e.g. a LFM chirp). Matched filtering then is applied at every receiver element with $h_i^j(-t)$ and these results are combined coherently across the M receiving elements for a given user [1-3]. Complexity of the channel is beneficial for time reversal communications yielding an aggregate response for each user after multichannel combining close to a delta function (expressed analytically as the summation of the autocorrelations of each channel impulse response and denoted by q(t) in [1-2]). After multichannel combining, each user signal is processed with a single channel decision feedback equalizer (DFE) to remove any residual intersymbol interference (ISI) and compensate for channel fluctuations during the packet transmission. This same approach can be applied in a synthetic aperture context where multiple transmissions (separated spatially) substitute for multiple receive elements [4].

As an alternative to the passive time reversal technique described above, an iterative equalization and decoding approach has been developed for recovering information transmitted through a shallow water communication channel [5]. The procedure has three main tasks: estimation of channel model parameters (CMPs), channel equalization, and decoding. These tasks are performed cyclically until the algorithm converges. Information bits are convolutionally encoded, punctured and permuted, mapped into QPSK symbols, linearly modulated, and transmitted. Training symbols are prepended to the transmitted sequence for initial estimation of the CMPs. The algorithm processes data from a single receive sensor.

Data received on a vertical array was processed and the performance of the algorithm for each sensor in the array evaluated. The data was collected during a July 2004 experiment with NURC in a shallow water region north of Elba Island, Italy. The sound speed structure and experimental geometry are shown in Fig. 1.

There is negligible Doppler spread in the received data. However, difference between transmitter and receiver clocks as well as slight motion of the receive array produces a nonnegligible compression of the received signals. Consequently, there is an observable Doppler “shift.” Nonuniform resampling of the data produces time series modeled as the output of a linear time-invariant system. Resampling and CMP estimation are done iteratively, in conjunction with equalization and decoding. Fig. 2 illustrates the SNR measured across the array, the channel impulse response (CIR) estimates for three of the array elements, and their respective sampling time offsets.

Fig. 3 illustrates the iterative process. It shows the linear equalizer (LE) output scatter plots for the first three iterations using data from Sensor 24. Successive improvement of the equalization step of the processing is demonstrated via an increase in LE output SINR from 2.1 to 8.0 dB. A further example showing the improvement in bit errors with iteration is shown in Fig. 4. Here the results are shown in tabular form for 7 of the array elements. The algorithm successfully processes the data to yield few or no information bit errors.

References

[1] H.C. Song, W.S. Hodgkiss, W.A. Kuperman, W.J. Higley, K. Raghukumar, T. Akal, and M. Stevenson, “Spatial diversity in passive time reversal communications, J. Acoust. Soc. Am. 120: 2067-2076 (2006).

[2] H.C. Song, W.S. Hodgkiss, W.A. Kuperman, T. Akal, and M. Stevenson, "Multiuser communications using passive time reversal," IEEE J. Oceanic Eng. 32(4): 915-926, DOI: 10.1109/JOE.2007.904311 (2007).

[3] H.C. Song, W.S. Hodgkiss, and S.M. Kim, "Performance prediction of passive time reversal communications (L)," J. Acoust. Soc. Am. 122(5): 2517-2518, DOI: 10.1121/1.2782820 (2007).

[4] H.C. Song, W.S. Hodgkiss, W.A. Kuperman, T. Akal, and M. Stevenson, "High-rate synthetic aperture communications in shallow water," IEEE J. Oceanic Eng. (submitted, 2008).

[5] J.F. Sifferlen, H.C. Song, W.S. Hodgkiss, W.A. Kuperman, and M. Stevenson, “An iterative equalization and decoding approach for underwater acoustic communication,” IEEE J. Oceanic Engr. 33(2): 182-197, DOI: 10.1109/JOE.2008.923552 (2008).

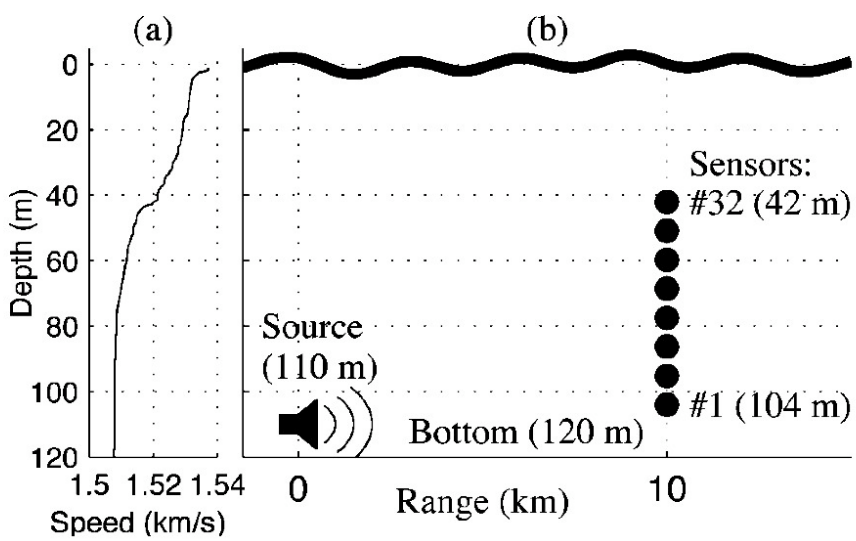

Figure 1. (1) Measured downward-refracting sound speed profile. (b) Shallow water experiment geometry north of Elba Island, Italy.

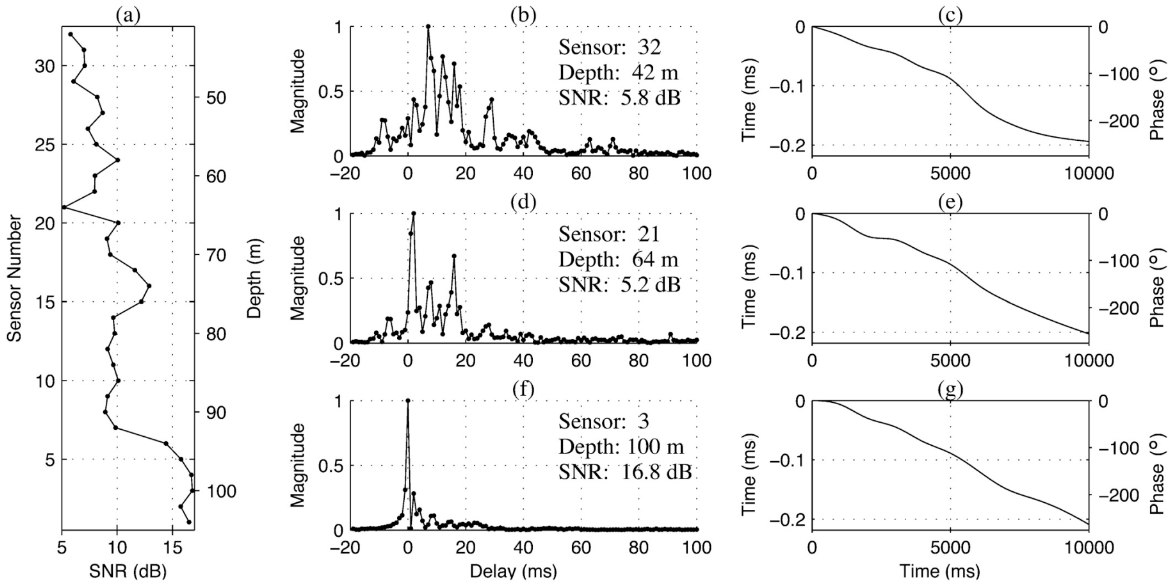

Figure 2. (a) SNR measured across entire array. Left axis is sensor number and right axis is sensor depth. (b) Channel impulse response (CIR) estimated for Sensor 32. (c) Estimated sampling time offset for Sensor 32. Right axis shows corresponding phase rotation. (d) and (e) CIR and sampling time offset for Sensor 21. (f) and (g) CIR and sampling time offset for Sensor 3.

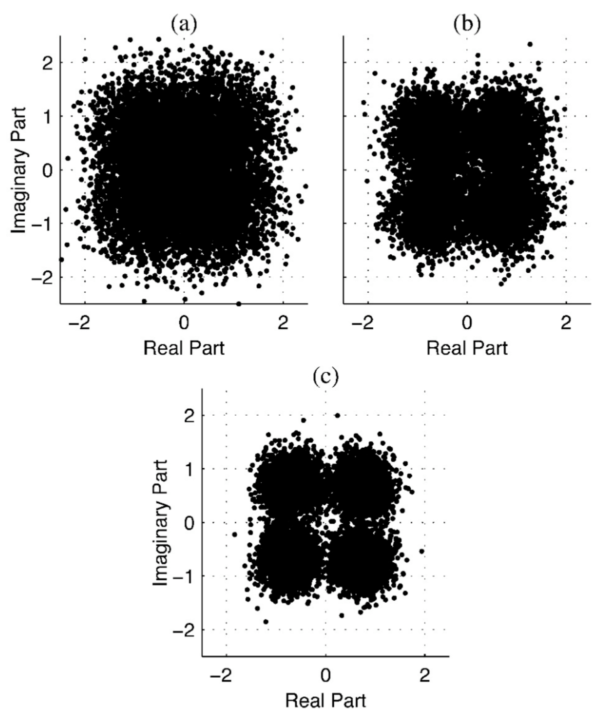

Figure 3. Scatter plots of the linear equalizer (LE) output for Sensor 24 illustrating iterative improvement in the equalization process. (a) First iteration: LE output SINR = 2.1 dB. (b) Second iteration: LE output SINR = 5.6 dB. (c) Third iteration: LE output SINR = 8.0 dB.

Sensor		21	22	26	29	30	31	32
Depth (m)		64	62	54	48	46	44	42
SNR (dB)		5.2	8.0	7.4	6.1	7.1	7.0	5.8
Iteration	1	1315	710	618	2033	1217	448	2679
	2	509	264	21	1110	281	12	2092
	3	159			494	6		1346
	4	32			155			739
	5	12			16			267
	6	5			10			81
	7	5						1
	8	5						
	9	5						
	10	5						

(Blank entries indicate zero errors)

Figure 4. Number of bit errors for the sensors with SNR below 8 dB.